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Recent Advancements in Fetal Programming

Abstract

With increasing environmental pressures, consumer demands and competition for agricultural inputs, the cattle industry will need to find new and innovative ways to improve cattle performance, while using fewer resources. In cow-calf production systems, low quality forages are often used to feed pregnant cows, which can lead to nutrient inconsistencies and opportunities for maternal undernutrition to occur. Fetal programming is one strategy that could mitigate these inconsistencies in cow-calf systems. Fetal programming is changing offspring performance by manipulating the maternal environment while offspring are still *in utero*. Fetal programming methodologies can be implemented, through positive maternal nutritional management, to improve the performance of their offspring potentially resulting in higher value cattle. The impacts of fetal programming, positive and negative, can influence post-natal performance, growth, health and reproductive abilities. Fetal programming highlights a unique opportunity for producers to influence cattle performance at the beginning, without significant inputs later in their production lifecycle. This paper brings together a review of key concepts in fetal programming with practical applications to real-world livestock production.

Introduction

In *Feeding Beef Cattle II* (Llewellyn et al., 2012), fetal programming as a management tool for improving cow-calf systems is introduced. Here, we will expand on those topics as well as discuss calf and producer benefits resulting from fetal programming. It is important to ensure that cattle are raised so that they can be healthy, productive, and as efficient as possible. To accomplish this, taking a systems approach to managing cattle is recommended, meaning looking not only at producing calves, but also considering their entire lifecycle and performance (Llewellyn et al., 2012). By looking at the entire scope of beef production, from conception to slaughter, the entire system can be improved incrementally. Ideally, cattle production efficiency and value can be increased while additional producer inputs are limited. This creates a need for cattle producers to find more sustainable practices for cattle management. One potential strategy to help address these challenges is to utilize fetal programming through strategic maternal nutrition management.

Cow-calf production is based on high forage diets, often consisting of range or pasture, which can vary in forage quantity and nutritional quality throughout beef cow pregnancy. The quality of pastures used in cow-calf systems often depends on environmental factors that are out of a producer's ability to control (Taylor et al., 2016). Poor pasture conditions can leave pregnant grazing cows in a negative energy status which leads to nutrient restrictions that can impact fetal calf development. Additionally, nutrient restriction of bred heifers, compared to mature cows can have amplified impacts on the fetal calf, including reduced birth weights resulting from both prolonged nutrient restriction and reduced protein intake (Greenwood and Cafe, 2007). This is mostly attributed to the ability of mature cows to compensate better for nutritional fluctuations compared to bred heifers, which are still growing in addition to being pregnant. The energy cattle can get from grazing forages is dependent on the total digestible nutrients (TDN) of the forage. Protein is not only a component of the TDN of a forage, but can also be supplemented into the diet to increase available energy, rumen microbial populations and improve cattle performance (Mathis, 2003). It is important to know the TDN of forages and adjust supplementation as necessary to improve intake and provide adequate energy for animal performance.

Traditionally, it has been thought that the late stages of pregnancy are the most important, because of large increases in fetal growth. However, there is evidence that nutrient restriction during early and mid-gestation has lasting impacts on fetal growth as well, particularly skeletal muscle development (Zhu et al., 2006). Changes in nutrition status during gestation can potentially influence desirable production attributes in the offspring later in life. Most studies that focused on maternal nutrient restriction noted correlations between altered nutrient status during early- to mid-gestation and changes in the muscle composition of offspring from restricted dams (Taylor et al., 2016). By understanding these changes and the causes, there is potential to improve offspring carcass traits through maternal nutritional management. Understanding how these nutritional changes in the dam affects fetal development and offspring performance could be an efficient tool to help produce calves which perform better from birth to slaughter.

What is Fetal Programming?

Fetal programming is impacting fetal development through altering the maternal nutritional environment causing developmental changes that will impact offspring performance (Funston et al., 2012). Changes can be both positive and negative depending on diet changes, duration, and the dam’s ability to compensate. The physical appearance of offspring may not differ from mild nutrient restriction of their dams, but calf genetic and muscle characteristics can be altered in a variety of ways such as decreased muscle growth and marbling (Paradis et al., 2017). In cases of severe nutrient restriction during pregnancy, there might be readily observable impacts to calves along with impacts on meat quality. Fetal programming can impact offspring muscle quantity and quality with some studies showing benefits related to other important production aspects.

Improving Beef Quality

Producers typically want healthy, productive cattle that will achieve high USDA quality grades and higher prices. Marbling is a main factor in the grading of beef and it is important to manage cattle to improve marbling (Meadows, 2013). The fetal stage of development plays a crucial role in the marbling potential, muscle development and postnatal growth of cattle. During early to mid-gestation, stem cells begin to form vital organs and structures in the fetus as well as differentiate into muscle fibers (Figure 1). The development of muscle fibers during the embryonic stages of development is called myogenesis. Reduction of myogenesis impacts the number of muscle cells that will be developed overall, and once the window of muscle fiber differentiation is closed, no more muscle fibers can be created in the fetus. Muscle fiber development is of lower priority compared to visceral organs, and so is impacted more heavily by poor maternal nutrition (Du et al., 2013). Maternal nutrient restriction during the early to mid-gestational period reduced the overall size and number of muscle fibers in the offspring, resulting in reduced muscling after birth (Du et al., 2013).

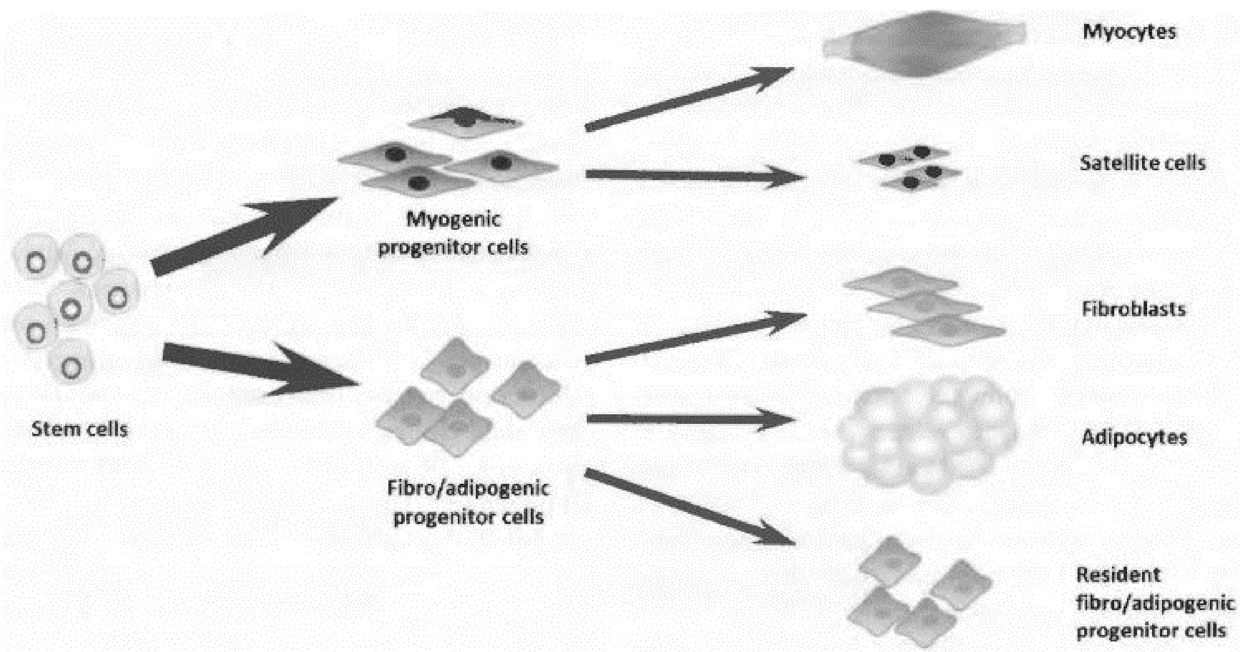

Figure 1: Muscle cells differentiation from stem cells during fetal development (Du et al., 2013).

Additionally, in mid-gestation, adipogenesis is initiated and this is also when intramuscular fat is deposited as secondary myogenesis starts to slow down (Figure 2; Du et al., 2010). In Figure 2 the different stages of myogenesis and adipogenesis can be seen as well as their progression/regression during development. Adipogenesis is the development of fat cells during embryonic development. Mid-gestation presents a unique window of opportunity to not only make sure calves will have adequate muscle cell differentiation, but also to improve marbling potential in calves and potentially to increase their quality grade at slaughter.

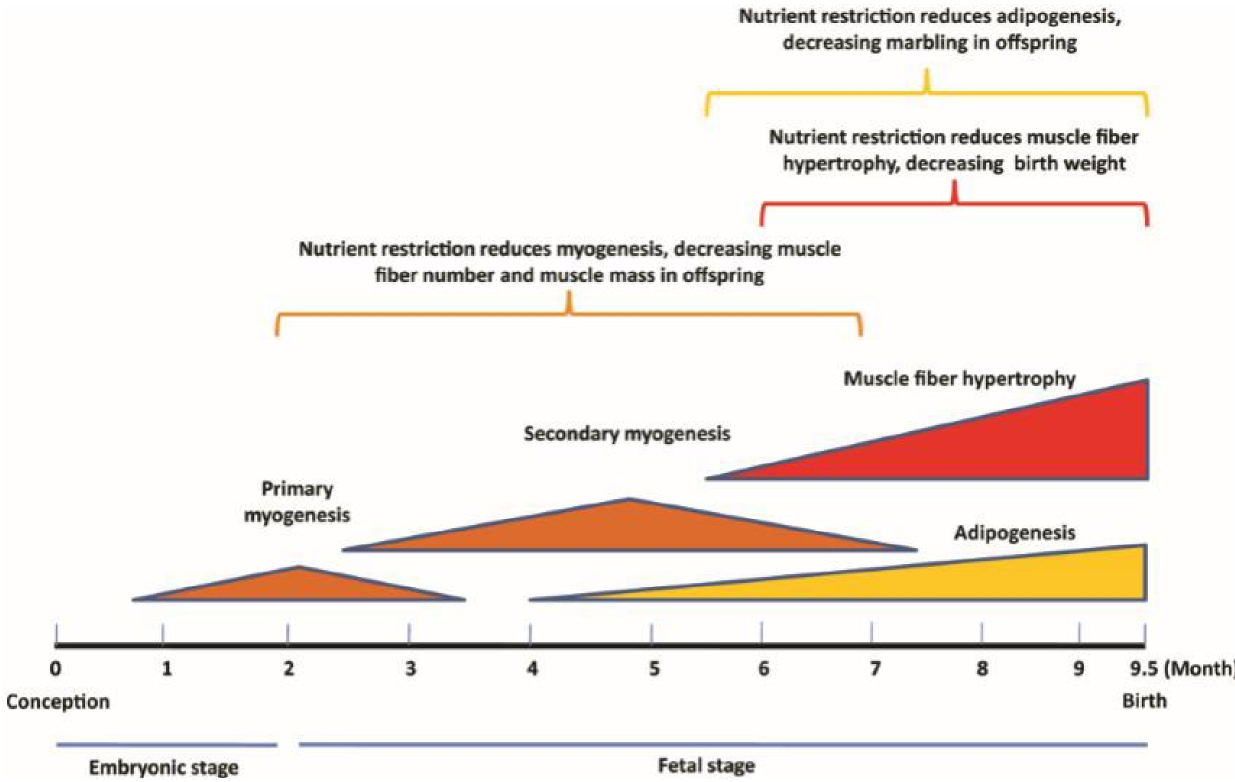

Figure 2: Myogenesis, adipogenesis and fibrogenesis waves during fetal development (Du et al., 2010).

Fat pregnant females can have impacts on yield and carcass quality of the offspring as well. In some studies, focusing on body weights, calf birth weights can be recovered through supplementation to dams later in gestation, after a period of nutrient restriction. However, the resulting calves may still have impacts on their muscle and fat composition depending on the period and duration of restriction or over conditioning. In the study by Micke et al. (2010), heifers fed a low crude protein diet (70% of NRC crude protein requirement) throughout the first and second trimesters of pregnancy had offspring with more marbling than those fed a high crude protein diet (240% of NRC crude protein requirement). During the second trimester adipogenesis increases, and so in this case overfeeding protein during gestation created increased fatness, but not necessarily marbling in the offspring. Changing management tactics throughout pregnancy to fit the dam’s changing requirements may be the most advantageous strategy to improve fetal myogenesis and marbling potential, along with benefiting cow health and recovery post pregnancy.

Steer Calves

Steer calves from dams that grazed improved pastures, as opposed to non-improved native range, had higher birth weights and higher carcass weights (Funston et al., 2012). When grazing cows on improved pastures from 120 to 180 days of gestation, it was observed that steer offspring had improved gains throughout production, final body weights and hot carcass weights, compared to steer calves from cows grazing native range pastures only (Funston et al., 2012). Additionally, steers from cows that grazed improved pasture or received protein supplementation on native range conditions had improved marbling scores and USDA quality grades at processing (Funston et al., 2012; Larson et al., 2009), as well as indications of increased tenderness of the meat (Long et al., 2009; Paradis et al., 2017). This suggests that supplementing dams during mid- to late-gestation gives their calves a lasting advantage in terms of body weight over calves from non-supplemented dams.

Heifer Calves

Heifers from protein supplemented dams did not have an advantage in birth weights, but did have increased body weights at weaning, increased pre-breeding weights and increased pregnancy diagnosis, as well as improved pregnancy rates (Funston et al., 2012). Heifers from cows supplemented with 42% CP during late gestation while grazing sub-irrigated meadow reached puberty earlier (14 days) and had higher pregnancy rates than heifers that were not supplemented (Funston et al., 2013). Better pregnancy rates are advantageous when utilizing heifers for replacement. Having the additional body weight going into pregnancy would potentially help these heifers be better able to cope with changing forage conditions and keep body condition throughout pregnancy.

Calf Health

Calf health may also be impacted by maternal nutrient restrictions that reduce body condition score (BCS) during pregnancy. A study from Taylor et al. (2016; Figure 3), found that severe nutrient restriction during mid-gestation resulted in a depressed antibody response to new pathogens in calves. Figure 3 shows ovalbumin levels following ovalbumin vaccination. Cows maintaining BCS (control) during mid-gestation compared with calves from cows losing BCS during mid-gestation (restricted). Ensuring pregnant cows are in a positive nutrient status, or that negative nutrient status is limited during gestation, helps to improve the immunological health of calves as they encounter new illnesses. Fetal calves rely on the innate immune response which develops toward the end of gestation and declines gradually in functionality due to increased levels of fetal cortisol as parturition approaches (Chase et al., 2008). After parturition calves rely on passive immunity transferred by colostrum from their dams until active immunity is developed, starting at 2-4 weeks of age and continuing to develop to full maturity at approximately 6 months of age (Chase et al., 2008).

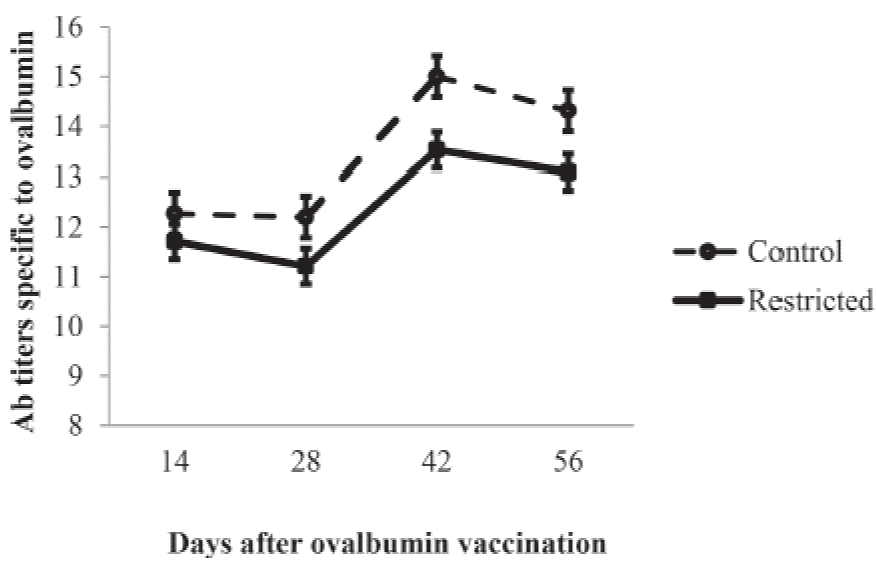

Figure 3: Antibody response over time (after injection with ovalbumin) of calves (Taylor et al., 2016).

Healthy, functional immunity is particularly important when cattle will be experiencing stressful events and encountering new environments as these are the times when new pathogens can be introduced to cattle and/or stress can decrease immune function (i.e. shipping and feedlot settings).

Strategies

Protein supplementation

The majority of studies caution against either severe nutrient restriction, such as 70% NRC requirement of crude protein, and/or severe over nutrition, such as 240% NRC recommended crude protein (Long et al., 2009; Micke et al., 2010). Even mild nutrient deficiencies can impact calf physiology in ways that may not be observed outwardly, and larger restrictions create more detrimental changes to calf health, performance and thriftiness that can impact their production value. The most positive outcomes for maternal supplementation have come from moderate crude protein supplementation, based on grazing conditions and balanced with cow/heifer nutrient requirements. Specifically, in a study by Stalker et al. (2007), cows grazing upland range conditions were given a 0.45 kg protein supplement (42% crude protein) three times per week over winter (December 1 to February 28). The resulting calves had improved marbling compared to calves from non-supplemented dams. Robinson et al. (2013), noted that fetal programming, which we know from substantial amounts of recent literature can be related to maternal nutrition, influence body weight, feed intake, carcass weight, muscle weights, meat yield, and fat and bone weights.

Fat supplementation

Providing adequate lipid content in the diet to support lipid metabolism is important to support immune functions, cow reproductive capacities, fertility and milk production (Hiller et al., 2014). However, too much dietary fat will cause decreased palatability and rumen microbe activity (Hiller et al., 2014) so it should be balanced in the diet according to NRC recommendations (National Academies of Sciences, Engineering, and Medicine, 2016). Supporting important maternal physiological functions through adequate lipid supplementation can be beneficial to both the dam and the calf. When calves are born, they are effectively moving onto a new diet as they begin to nurse, meaning the quality of milk produced by dams becomes significantly important for calf nutrition and growth (Robinson et al., 2013). Neonatal growth and nutrition are important to later health status and performance, so considering postpartum nutrition is important as well.

Conclusions

Maternal nutrient restriction of beef cattle causes deleterious impacts on the fetus that will continue to influence the calf throughout its life. Though in some instances these changes are observable, often the outward appearance of these calves is generally indiscernible, despite genetic and muscular composition being changed (Paradis et al., 2017). Through considering pasture availability and conditions, cattle type and characteristics, as well as desired production goals, there can be benefits from implementing fetal programming to cow-calf operations. The benefits of fetal programming on calf health, performance and beef quality show promise for producers to improve cattle production without significantly altering inputs. Continued research and application of fetal programming could greatly help produce more high-quality beef, using fewer inputs while maintaining or reducing cattle numbers. In a practical sense, providing high-quality nutrition at critical times during the cows' production cycle (but not overfeeding) takes advantage of fetal programming and maternal response that has far reaching implications (many of them positive) for offspring later in life.

Literature Cited

Chase, C.C.L., J.D. Hurley, and A.J. Reber. 2008. Neonatal immune development in the calf and its impact on vaccine response. *Veterinary Clinics of North America: Food Animal Practice* 24(1): 87-104. https://doi.org/10.1016/j.cvfa.2007.11.001.

Du, M., Y. Huang, A.K. Das, Q. Yang, M.S. Duarte, M.V. Dodson, and M. Zhu. 2013. Meat science and muscle biology symposium: manipulating mesenchymal progenitor cell differentiation to optimize performance and carcass value of beef cattle. *Journal of Animal Science* 91(3): 1419-1427. doi:10.2527/jas.2012-5670.

Du, M., J. Tong, J. Zhao, K.R. Underwood, M. Zhu, S.P. Ford, and P.W. Nathanielsz. 2010. Fetal programming of skeletal muscle development in ruminant animals. *Journal of Animal Science*, 88(S13): E51-E60. doi:10.2527/jas.2009-2311.

Funston, R., A. Summers, and A. Roberts. 2012. Alpharma beef cattle nutrition symposium: implications of nutritional management for beef cow-calf system. *Journal of Animal Science* 90(7): 2301-2307. doi:10.2527/jas.2011-4568.

Funston, R., and A. Summers. 2013. Epigenetics: setting up lifetime production of beef cows by managing nutrition. *Annual Review of Animal Biosciences* 1(1): 339-363. doi:10.1146/annurev-animal-031412-103649.

Greenwood, P.L., and L.M. Cafe. 2007. Prenatal and pre-weaning growth and nutrition of cattle: long-term consequences for beef production. *Animal* 1(09): 1283-1296. doi:10.1017/s175173110700050x.

Hiller, B. 2014. Recent developments in lipid metabolism in ruminants – the role of fat in maintaining animal health and performance. *Animal Production Science* 54(10): 1549-1560. doi:10.1071/an14555.

Larson, D. M., J.L. Martin, D.C. Adams, and R.N. Funston. 2009. Winter grazing system and supplementation during late gestation influence performance of beef cows and steer progeny. *Journal of Animal Science* 87:1147–1155.

Llewellyn, D., S. Smith, and M. Du. 2012. Feeding beef cattle II: rethinking feeding programs. *Washington State University Extension EM060E*. https://s3.wp.wsu.edu/uploads/sites/2071/2013/07/Llewellyn-et-al_Feeding-Beef-Cattle-II_Rethinking-Feeding-Programs_EM060E.pdf.

Long, N., K. Vonnahme, B. Hess, P. Nathanielsz, and S. Ford. 2009. Effects of early gestational undernutrition on fetal growth, organ development, and placentomal Composition in the Bovine1.” *Journal of Animal Science* 87(6): 1950–1959. https://doi.org/10.2527/jas.2008-1672.

Mathis, C.b P. 2003. Protein and energy supplementation to beef cows grazing New Mexico rangelands. *New Mexico State University Cooperative Extension Service. Circular 564*. https://aces.nmsu.edu/pubs/_circulars/Circ564.pdf.

Meadows, L. 2013. What's your beef—prime, choice or select? *USDA Blog*. Accessed April 8, 2019. https://www.usda.gov/media/blog/2013/01/28/whats-your-beef-prime-choice-or-select?page=1.

Micke, G., T. Sullivan, K. Gatford, J. Owens, and V. Perry. 2010. Nutrient intake in the bovine during early and mid-gestation causes sex-specific changes in progeny plasma IGF-I, liveweight, height and carcass traits. *Animal Reproduction Science* 121(3-4): 208-217. doi:10.1016/j.anireprosci.2010.05.017.

National Academies of Sciences, Engineering, and Medicine (NRC). 2016. *Nutrient Requirements of Beef Cattle: Eighth Revised Edition*. National Academies Press. https://doi.org/10.17226/19014.

Paradis, F., K.M. Wood, K.C. Swanson, S.P. Miller, B.W. McBride, and C. Fitzsimmons. 2017. Maternal nutrient restriction in mid-to-late gestation influences fetal mRNA expression in muscle tissues in beef cattle. *BMC Genomics* 18(1): 1-14. doi:10.1186/s12864-017-4051-5.

Robinson, D.L., Cafe, L. M., and Greenwood, P. L. 2013. Meat Science And Muscle Biology Symposium: Developmental programming in cattle: Consequences for growth, efficiency, carcass, muscle, and beef quality characteristics. *Journal of Animal Science*, 91(3), 1428-1442. doi:10.2527/jas.2012-5799.

Stalker, L., L. Ciminski, D. Adams, T. Klopfenstein, and R. Clark. 2007. Effects of weaning date and prepartum protein supplementation on cow performance and calf growth. *Rangeland Ecology and Management* 60(6): 578–587. https://doi.org/10.2111/06-082R1.1.

Taylor, A., D. Mohrhauser, R. Pritchard, K. Underwood, A. Wertz-Lutz, and A. Blair. 2016. The influence of maternal energy status during mid-gestation on growth, cattle performance, and the immune response in the resultant beef progeny. *The Professional Animal Scientist* 32(4): 389-399. doi:10.15232/pas.2015-01469.

Zhu, M.J., S.P. Ford, W.J. Means, B. Hess, P.W. Nathanielsz, and M. Du. 2006. Maternal nutrient restriction affects properties of skeletal muscle in offspring. *The Journal of Physiology* 575(1): 241-250. doi:10.1113/jphysiol.2006.112110.